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The Floating Potential Probe (FPP) for ISS - Operations and Initial Results

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ABSTRACT

In this paper we report early results from the Floating Potential Probe (FPP) recently installed on the International Space Station (ISS). The data show that FPP properly measures the electrical potential of ISS structure with respect to the plasma it is flying through. FPP Langmuir probe data seem to give accurate measurements of the ambient plasma density, and are generally consistent with the IRI-90 model. FPP data are used to judge the performance of the ISS Plasma Contacting Units (PCUs), and to evaluate the extent of ISS charging in the absence of the PCUs..

INTRODUCTION

It has been clearly understood for some time (refs. 1,2) that the International Space Station (ISS), by virtue of its high voltage (160 V) primary power generation system, will have important interactions with the ambient plasma in which it orbits. For instance, the negative grounding scheme of its solar arrays would cause the entire ISS structure to act as an ambient ion collector to compensate for the electrons collected by its more positive solar arrays. Models have shown that, in the absence of any mitigation, ISS structure would float at electrical potentials highly negative of its surrounding plasma (ref. 3). Such potentials are greater than those that could be stood-off by the anodized aluminum surfaces on ISS (ref. 4), so that ISS would arc due to dielectric breakdown. These arcs could have consequences ranging from a steady degradation of ISS surface thermal properties to possibly life threatening currents flowing through an astronaut's space suit (ref. 5). In order to control the ISS "floating potential," a set of Plasma Contacting Units (PCUs) have been installed near the ISS structure midpoint, and have been operating for six months now (ref. 6). By emitting a highly conductive xenon plasma, these PCUs can efficiently emit electrons collected by the solar arrays, and thus keep the ISS structure at nearly the same potential as its surrounding plasma, so-called "plasma ground." Proper PCU operations have been shown in ground-based plasma testing to tightly control structure potentials. On-orbit, PCU emission currents and anode voltages are monitored to help ascertain PCU health. However, in order to guarantee proper PCU potential clamping, a direct measure of the ISS floating potential with respect to its surrounding plasma was required.

THE FLOATING POTENTIAL PROBE

It was decided by the ISS program to build, fly and deploy on ISS structure (by the mission 4A on which the large high voltage solar arrays would be deployed) a probe to directly measure the potential of ISS structure with respect to the ambient plasma. Because of its job to measure the ISS "floating potential," it was dubbed the Floating Potential Probe (FPP). Because of the exceedingly short time until 4A launch, only a probe built up almost exclusively from space qualified parts and components, and with the simplest possible interfaces with ISS systems, could be constructed and qualified in time.

FPP was designed around two probes and their electronics that had already successfully flown on the STS-62 Space Shuttle payload experiment called SAMPIE (for Solar Array Module Plasma Interactions Experiment, see ref. 7). These were called the V-body probe (to measure the "body potential" of a spacecraft) and a Langmuir probe (to measure the ambient plasma density and temperature). Power was to be supplied to FPP by two small solar arrays of ISS solar array design which had already been space qualified for another experiment. An ISS astronaut helmet light battery would be used to store power. Data would be telemetered to the ISS Unity Node through a slightly modified WIS (Wireless Instrumentation System), which had flown successfully several times on the Space Shuttle.

FPP was mounted on ISS a sufficient distance from the PCUs that it would not be in their plasmas and in a position that during normal ISS operation would not be in the ambient plasma "wake" of any large structure. It was decided to mount FPP on top of the P6 truss element, where the large U.S. solar arrays were mounted. Standard ISS attachment points and hardware would be used to make astronaut training easier. FPP was launched in soft stowage aboard STS-97, the U.S. solar array deployment mission, and was attached at the top of P6 during a special extra-vehicular activity (EVA) period near the end of the mission. Astronauts Carlos Noriega and Joe Tanner deployed FPP on ISS on December 7, 2000, and data was first obtained from the probes on the following day.

In figure 1 the FPP may be seen as it appeared after ground-testing. The gold-color of the main "crate" is due to atomic oxygen-protected kapton, used for on-orbit thermal control. The two probes themselves (2 inches in diameter and on the ends of booms) may be seen extending from the face of the crate. The two solar arrays are also on booms, extending from the sides of the crate. The wireless communication antenna is a conical shape mounted on one side of the crate. GRC engineers specified the peculiar solar array orientations to optimize power generation from the non-tracking arrays during normal ISS flight attitudes.

Figure 2 is a drawing of FPP as installed on ISS. Here, the view is looking down from above P6, with aft to the lower right and starboard to the upper right. You can see the main solar array joint cylinders forward starboard and port of FPP. The probes stick out to port, the solar arrays mainly forward and aft, and the entire crate assembly is on a lengthy stanchion extending up from P6. A ground wire extends from FPP to the lower right to ISS structure.

FPP DATA-TAKING

FPP data files consist of housekeeping data (temperatures, voltages, battery charging currents, etc.), V-body measurements (in volts), and Langmuir probe bias voltages and the collected currents (in logarithmic form). For each of 200 timesteps of 0.1 seconds each, the FPP Langmuir probe voltage is stepped from +10 V to -5 V, and both a Langmuir probe current reading and V-body probe voltage reading is recorded. After the data are transmitted back through an antenna on the Unity Node, the V-body data are displayed to the astronauts inside Unity on a laptop computer, and then all data are stored for relay to the ground.

Since December 8, 2000, hundreds of hours of data have been obtained from FPP. The data are of high quality. Noise in the V-body readings is typically much less than one volt, and most of the Langmuir probe traces may be reduced for plasma density and temperature. FPP was located almost vertically above the ISS PCU during most data-taking sessions. Operationally, this means that because of the $\vec{v} \times \vec{B}$ effect of ISS motion through Earth's magnetic field, FPP is usually a few volts positive of the PCU. ISS structure floating potentials can in principle be obtained at any point by correcting for the $\vec{v} \times \vec{B}$ effect through models of the ISS orbit, ISS attitude, and the Earth's magnetic field. We used the ISS official plasma tool, the Environments Workbench (ref. 9) to find from the FPP V-body data the potential of ISS at the PCU, where it is being held by PCU action at the "clamping voltage" relative to the ambient plasma. This PCU clamping voltage was anticipated from ground-based testing to be some 10 to 15 volts negative of the ambient plasma.

In figure 5 are shown typical V-body readings of the FPP, averaged over the twenty second Langmuir probe sweep interval, versus GMT time, with one of the PCUs in operation. As can be seen, they vary in a sinusoid-like fashion over the 5460 second ISS orbital period. Part of this variation is due to $\vec{v} \times \vec{B}$ between the PCU and the FPP. Part, however, is caused by real variations in the PCU potential as it must emit varying electron currents as the ionospheric plasma density varies on the U.S. solar array electron collectors. In the laboratory, it has been seen that the so-called I-V characteristic of PCUs shows a shallow dependence of the emission current until near the "clamping voltage," whereupon it rises steeply. A PCU acts somewhat like a zener diode, to keep its potential at or below the clamping voltage with respect to its surroundings.

Figure 6 shows the data of figure 5 along with an overlay of the day and night portions of the orbit (calculated with EWB, using ISS orbital parameters), and the $\vec{v} \times \vec{B}$ voltage between the FPP and the PCU. Here, subtracting the $\vec{v} \times \vec{B}$ effect, we have determined the PCU floating potential. Several things can be seen in this picture. First of all, the PCU generally clamps its potential to a less negative voltage at night compared to daylight operation. This reflects the increased plasma density on the daylight side (but is complicated by the varying number of active [unshorted] solar array strings during daylight operation).

PCU I-V CHARACTERISTIC

In figure 7, we have plotted the PCU potential from Figure 6 versus the so-called "integrated emission current" from PCU2 (obtained from the standard ISS housekeeping data stream) as it was recorded. The "integrated emission current" is obtained by digitally differentiating the charge emitted by the PCU over each one second period. In the data-stream, and as plotted here, this number is actually 10 times the instantaneous emission current. It can be seen that there is a tight relationship between the current and the voltage over the range for which we have data. PCU2 seems to be doing its job of holding the ISS potential near to the plasma potential even better than had been anticipated.

The Shuttle bell nozzles acted as supplemental current collectors during the FPP data period analyzed here.

FPP LANGMUIR PROBE RESULTS

Using improved techniques developed to determine the LEO plasma density and temperature on the SAMPIE experiment (ref. 8), we analyzed the Langmuir probe traces from the new FPP data. Most of the Langmuir probe traces were consistent with fits for density and temperature. Chi^2 tests for goodness of fit were performed, and only traces with a very good fit are plotted here. In figure 8 may be seen the plasma density versus GMT time for these "good" traces for the first day of FPP operation. Along with the FPP results is shown the predicted ISS ionospheric electron density from the IRI-90 model in Environments Workbench (refs. 9 and 10). It is obvious that the FPP densities follow the IRI predictions very closely except near the beginning of data taking. It was later determined that during this initial period, ISS was in a "free drift" attitude mode, and the very low densities were the result of FPP being in the wake of some major ISS structure.

Using the same "good" traces as above, we plot in figure 9 the FPP electron temperature data. The FPP electron temperatures are everywhere greater than the IRI predictions, and sometimes are a full factor of two greater than the oft-quoted 0.25 volt ionospheric maximum. This behavior has been seen often in the months since FPP started operating, and we ascribe it to the extreme level of solar activity during this period.

In figure 10, we plot the 20 second averaged V-body readings versus the plasma voltage determined from the Langmuir probe fits. Here, one can see that the V-body readings and the Vplasma readings are highly correlated with each other, as must be true if both are indications of the FPP potential with respect to the ambient plasma. It is also clear that the V-body scatter is much smaller than that of Vplasma, and is smaller than one volt. A plot of the V-body readings during several Langmuir probe traces (not shown here) indicates that the V-body probe is beginning to be affected at the highest voltages of the Langmuir probe sweep. However, the V-body reading is increased by less than 0.25 volt at these times, well within the V-body noise.

CONCLUSIONS

The first day's data from the Floating Potential Probe on the International Space Station have been analyzed. The V-body and Langmuir probe data are of high quality, and can be used to determine the ISS floating potential and the plasma conditions through which ISS flies if the probe data ranges are not violated. Scatter in the 20 second V-body averages is much less than one volt. FPP V-body data have been used to determine a relationship between floating potential and current for the ISS Plasma Contactor Unit #2. This relationship may be used to improve predictions of ISS floating potential when PCU2 is operating nominally. FPP has confirmed nominal PCU2 floating potential control for approximately 3 of the 3.75 total hours. FPP Langmuir probe traces have been used to determine the ambient plasma density and temperature. While the density readings closely reproduce the IRI-90 ionospheric model, the electron temperature values are higher than IRI predicts. FPP operation was shown to be disturbed by simultaneous operation of two PCUs, but can still be used to detect out-of-specification ISS floating potentials even at those times.

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